REMARKS/ARGUMENTS

Claims 19 and 20 have been added. Claims 1-20 are pending.

The Examiner provisionally rejected claims 1-18 under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1-17 of copending Application No. 10/318,612. A terminal disclaimer is attached.

The Examiner rejected claims 1-3 and 17 under 35 U.S.C. 102(b) as being anticipated by Motoda; Takashi et al. (US 5,496,408 A). Motoda; Takashi et al. does not disclose a master fixed orifice and a first slave leg fixed orifice. The Examiner cites the Webster's Collegiate Dictionary to broadly define orifice as an opening and then states that all piping has an orifice. The term "orifice" used in the phrase "fixed orifice" is a term of art used in fluid flow. The attached reference from a U.S. Government web site states that "An orifice as used as a measuring device is a well-defined, sharp-edged opening in a wall or bulkhead through which flow occurs." To be used as a measuring device to precisely control flow, the opening size must be clearly defined and known, which is not true for just any opening in a pipe. Motoda does not disclose the use of such a fixed orifice. In addition, a section from the SAE AEROSPACE APPLIED THERMODYNAMICS MANUAL is submitted, which describes different head meters on page 402, section 4.1. The orifice is defined as one head meter of 5 described head meters. The characteristics of the orifice are described and defined. For at least these reasons, claim 1 is not anticipated by Motoda; Takashi et al..

The Examiner rejected claims 4-7, 9, 10, 12, and 15 under 35 U.S.C. 103(a) as being unpatentable over Motoda; Takashi et al and in further view of Shinozuka; Shyuhei et al. (US 6,315,858).

The Examiner rejected claims 8, 11, 13, 14, 17, and 18 under 35 U.S.C. 103(a) as being unpatentable over Motoda; Takashi et al and Shinozuka; Shyuhei et al. in view of Ohmi; Tadahiro et al. (US 5,313,982).

Claim 18 recites that the fixed orifice is a flat plate fixed orifice. Page 29, lines 5-16, and FIG. 19 of the present application define and illustrate a flat plate fixed orifice as being a tube 1904 with a flat plate 1980 with a fixed aperture placed across the diameter of the tube to define the orifice area. The Examiner failed to point out anything in the cited references that teaches this. The Examiner stated that Shinozuka teaches a flat plate fixed orifice (39, Figures 5, 6). Col. 7, lines 21-25, of Shinozuka states that device 39 is an iris device 39 (nozzle aperture varying device) that is that is operated by a motor. Therefore, such a device is not a fixed orifice. For at least these reasons claim 18 is not made obvious by Motoda; Takashi et al and Shinozuka; Shyuhei et al. in view of Ohmi; Tadahiro et al. (US 5,313,982).

Dependent claims 2-17 are also patentably distinct from the cited references for at least the same reasons as those recited above for the independent claim, upon which they ultimately depend. These dependent claims recite additional limitations that further distinguish these dependent claims from the cited references.

For example, claims 8 and 13-14 further recite a zone selection device connected to the master leg down stream from the master fixed orifice. The Examiner stated that the motivation for combining Motoda and Shinozuka and Ohmi is taught by Shinozuka's "monoblock valves" (col. 9, lines 5-10). It would not be obvious to combine the teachings of Shinozuka with Motoda. Shinozuka is for a gas polishing system, see abstract. The Examiner failed to point out anything in the cited references that teaches that the monoblock for minimizing "dead zones" in Motada or Shinozuka would be desirable.

In addition, claims 9-12 and 15 further recite that the fixed orifices are fixed plate orifices. As discussed above, page 29, lines 5-16, and FIG. 19 of the present application define and illustrate a flat orifice as being a tube 1904 with a flat plate 1980 with a fixed aperture placed across the diameter of the tube to define the orifice area. The Examiner failed to point out anything in the cited references that teaches this. The Examiner stated that Shinozuka teaches a flat plate fixed orifice (39, Figures 5, 6). Col. 7, lines 21-25, of Shinozuka states that device 39 is an iris device 39 (nozzle aperture varying device) that is that is operated by a motor. Therefore, such a device is not a fixed orifice. For at least these reasons the dependent claims are not anticipated or made obvious by the cited references.

New claims 19 and 20 are dependent on claims 18 and 1, respectively, and further recite a joining manifold for combining output from the first slave leg, the second slave leg, and the third slave leg connected between the first slave leg, the second slave leg, the third slave leg and a zone of the at least two zones of the process chamber. For at least this reason, new claims 19 and 20 are not anticipated or made obvious by the cited art.

Applicants believe that all pending claims are allowable and respectfully request a Notice of Allowance for this application from the Examiner. Should the Examiner believe that a telephone conference would expedite the prosecution of this application, the undersigned can be reached at telephone number (650) 961-8300.

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CHAPTER 9 - SUBMERGED ORIFICES

1. Definition and Classification of Orifices

An orifice used as a measuring device is a well-defined, sharp-edged opening in a wall or bulkhead through which flow occurs. Orifices may be used to measure rates of flow when the size and shape of the orifices and the heads acting upon them are known. For irrigation use, orifices are commonly circular or rectangular in shape and are generally placed in vertical surfaces, perpendicular to the direction of channel flow.

A submerged orifice and the same orifice discharging freely have nearly the same coefficient of discharge. Submerging an orifice provides the capability to measure relatively large flows with a small drop in water surface, conserving delivery head compared with weirs. However, the submerged orifice requires head measurements upstream and downstream. The difference between the two heads is used in the orifice equation (equation 9-1). A free- flow measurement requires measurement of only one upstream head.

Using an orifice as a water measuring device demands attention to dimensions and craftsmanship, and the orifice must closely simulate conditions existing when it was calibrated. Equation coefficients depend on these details and can vary considerably. For full contraction, the orifice plate should be machined around the entire perimeter of the opening to a clean, straight, and sharp upstream edge and corner in the direction of the flow. Rounding of an upstream face corner can partially or fully suppress contraction. For example, 1-percent rounding of the upstream face corner of the opening perimeter in terms of minimum orifice opening dimension causes about a 3-percent increase of the contraction coefficient. A well-designed bellmouth will eliminate all contraction (Schuster, 1970).

Orifices may be partially contracted in two senses. One is the amount of curvature of the jet in the direction of flow and the other in the amount of orifice opening perimeter which produces no curva-ture of the jet passing through the opening. The latter is called suppression. An example of a partially suppressed orifice is a sluice gate, where the approach boundary on the sides and bottom continues past the sharp edge of the gate leaf above. This arrangement eliminates the jet contraction along part of the orifice opening perimeter, increasing the effective coefficient of discharge.

Coefficients are used in equations to account for: neglecting the approach velocity head, the approach velocity distribution, the decrease of jet velocity caused by friction, and the amount of jet contraction caused by the flow curving around the corner of the orifice perimeter.

The proximity of the upstream water surface to the top of the orifice opening affects the amount of contraction. For full contraction, the water surface upstream from the orifice must always be well above the top of the opening. Similar to weirs, if the bottom or the side walls of the approach channel are too close to the orifice edges, then the sides and bottom of the orifice jet are not fully contracted. If the upstream water surface drops below the top of the opening, the opening, in effect, becomes a weir.

SAE AEROSPACE
APPLIED THERMODYNAMICS MANUAL

DEVELOPED BY
SAE COMMITTEE AC-9, AIRCRAFT ENVIRONMENTAL SYSTEMS

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compilation of fluid meter data. As nearly as possible, the nomenclature of this section is consistent with that work.

4.1 CHARACTERISTICS OF THE HEAD METERS

4.1.1 *Selection of the Proper Head Meter*—Each of the principle head meters have particular attributes that influence their suitability for a particular application.

Advantages:

(1) Orifice—Most versatile, least expensive, and probably the most accurate of the heat meters for general laboratory application; unsuitable for dirty fluid or slurries; fairly high unrecoverable pressure loss.

(2) Nozzle—More accurate than an orifice for supercritical pressure ratios; handles dirty fluids and slurries better than an orifice; more expensive than an orifice to machine; unrecoverable pressure loss about the same as an orifice.

(3) Venturi Tube—Characteristics similar to a nozzle except for the very low pressure loss, making it particularly suitable for applications where savings in pumping power are important.

(4) Pitot-Static Tube—Offers negligible line restriction; possible to traverse where skewed velocity profile might invalidate another type of head meter, but traversing cumbersome and time consuming; cannot be used where velocity pressure is low.

(5) System Line Loss—A test technique for flow measurement without introducing meter disturbance; limited accuracy; requires calibration; calibration may be very sensitive to variable upstream system geometry, for example, valve position.

Disadvantages: All head meters have several basic disadvantages, which for a particular application may encourage the use of one of the other meter types discussed later. These disadvantages are:

(1) Limited flow range for a given metering arrangement. For example, an orifice plate producing a 30 in. H_2O differential on a U-tube manometer at full flow can be utilized only down to 20 to 30% of full flow with reasonable accuracy.

(2) The usual application requires a flow computation, making the setting of a desired flow more difficult than with a direct indicating meter. Totaling varying flows over a time interval is difficult.

(3) Behavior of head meters with pulsating flow is uncertain and the subject of continuing research (Ref. 25).

4.1.2 *Basic Equation*—The equations used for computing flow through nozzles, venturi tubes, and orifices usually are simplified forms of the basic nozzle equation, with empirical coefficients and corrections as required. Intelligent use of these simplified forms requires an examination of this equation, which can be derived from the general energy equation, the adiabatic relationship, and the continuity equation. For fluid meter applications the equation is usually arranged as

$$W = \underbrace{\frac{C}{\sqrt{1-\beta^4}}}_{(A)} \cdot \underbrace{\left[\frac{\gamma}{\gamma-1}\,\frac{(1-\beta^4)\left(1-r\,\frac{\gamma-1}{\gamma}\right)}{(1-\beta^4 r^2/\gamma)(1-r)}\,r^{2/\gamma}\right]}_{(B)} \cdot \underbrace{A_2}_{(C)}\,\underbrace{\sqrt{2g(\rho g)_1(P_1-P_2)}}_{(D)} \qquad (3G\text{-}10)$$

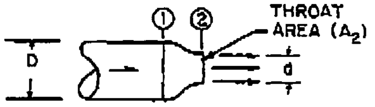
where the labeled expressions:

(A) = Flow coefficient K corrected for velocity of approach, dimensionless

(B) = Adiabatic expansion term Y_a, dimensionless

(C) = Nozzle area, ft^2

(D) = Flow velocity term, (lb/sec)/ft^2



It will be noted that the flow velocity term is incompressible in form and contains the upstream density, which is more readily measurable. Actually, the weight flow is proportional to the product of the throat velocity and the throat density. Thus the Y_a term may be thought of as a correction factor applied to the incompressible flow velocity term to account for these effects. It also follows that for incompressible fluids, $Y_a = 1$. The discharge coefficient C results from the fact that in a real fluid the boundary layer buildup along the nozzle walls prevents full utilization of the entire throat area at the predicted velocity.

For an orifice, the point of minimum flow area occurs downstream at the vena contracta. Because the vena contracta diameter and area ratio are indeterminate, the actual orifice dimensions are used and the flow coefficient K and expansion term (designated Y_1 for orifices) are empirical.

4.1.2.1 Specific Forms of the Basic Equation—Assignment of units, as indicated in Table 3G-9, to the basic flow equation

$$w = KYA_2\sqrt{2g(g\rho)_1(P_1-P_2)} \qquad (3G\text{-}11)$$

results in the equations of Table 3G-9, where $g\rho$ is always in lb/ft^3.

4.1.3 *Corrections Common to All Head Meters*—While the individual types of meters have characteristics that will be treated in detail in later subsections, there are certain corrections basic to all head meters.

4.1.3.1 Thermal Expansion—The area A_2 used in Eq. 3G-10 must be the true area at operating conditions. Since the diameter of the element is usually measured at room temperature, a correction factor should be applied to determine the area at elevated temperatures. From Fig. 3G-25,

$$(A_2)_{T_E} = F_a(A_2)_T = 70\text{ F}$$

4.1.3.2 Density Corrections for Compressibility and Humidity—The perfect gas law, commonly used to compute density, adequately describes real gas behavior only in a limited region. For example, with air at pressures from 0 to 200 psia and tempera-

Table 3G-9 Forms of Basic Equation

Equation	Units		
	w	ρ	A or d
$w = 8.022KYA_2\sqrt{(g\rho)_1(P_1-P_2)}$	lb/sec	psf	ft^2
$w = 96.26KYA_2\sqrt{(g\rho)_1(P_1-P_2)}$	lb/sec	psi	ft^2
$w = 40.11KYA_2\sqrt{(g\rho)_1(P_1-P_2)}$	lb/min	psi	in.^{2}
$w = 28.06KYA_2\sqrt{(g\rho)_1(P_1-P_2)}$	lb/min	in. Hg*	in.^{2}
$w = 7.617KYA_2\sqrt{(g\rho)_1(P_1-P_2)}$	lb/min	in. H_2O*	in.^{2}
$w = 5.982KYd^2\sqrt{(g\rho)_1(P_1-P_2)}$	lb/min	in. H_2O*	in.

*At 68 F.

tures above 60 F, the perfect gas law is within 0.5%. Deviations from perfect gas behavior can be accounted for by using the compressibility factor Z, such that

$$\rho g = \frac{P}{ZRT} \qquad (3G\text{-}12)$$

For air, the trend in variation of Z is shown in Fig. 3G-26. Compressibility factors for the common gases can be found in Refs. 26 and 27. In some applications a choice of meter locations will permit elimination of this correlation.

Where the gas being metered contains water vapor, a correction is necessary to the density, computed on a dry gas basis. The corrected wet gas density may be obtained as follows:

$$(\rho g)_{\text{wet gas}} = (\rho g)_{\text{dry gas}} \left[\frac{1+\omega}{1+(M_t\omega/18.01)}\right] \qquad (3G\text{-}13)$$

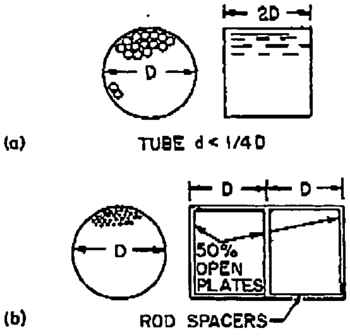
and for air,

$$(\rho g)_{\text{wet air}} = (\rho g)_{\text{dry air}} \left[\frac{1+\omega}{1+1.608\omega}\right] \qquad (3G\text{-}14)$$

Humidity effects on other terms in the flow equation are generally negligible (Ref. 3).

4.1.4 *Proper Meter Installation*—The head meters are seriously influenced by disturbing upstream and downstream conditions. While data exists (Ref. 28) for the requisite straight lengths preceding and following the meter for various kinds of disturbances, the conservative rules in Table 3G-10, with reference to the illustration (parts a and b), should be adequate.

For all β ratios above 0.70 and for β ratios above 0.4, when preceded by bends in different planes, it becomes desirable to use a flow straightener. In fact any general purpose laboratory metering section should be so equipped. Two accepted designs for flow straighteners are shown in the next illustration.



Although it introduces a higher pressure loss (about 10 times the duct velocity pressure), the perforated plate straightener has been shown to be superior to either the packed tube or the egg crate type of flow straightener (Ref. 29). The straightener should be installed 10 dia upstream of the meter and should be preceded by an additional 2 dia of straight pipe.

4.2 THE FLOW NOZZLE

4.2.1 *Nozzle Geometry and Discharge Coefficients*—The three most common nozzle designs are illustrated in Fig. 3G-27. The ASME nozzles usually are used with pipe-wall taps. The ISA nozzle with corner taps is used extensively in Europe. The ASME nozzles with pipe-wall taps are preferable, since an upstream corner tap tends to pick up some impact pressure, whereas the expansion factor Y_a is based on static pressures.

The ASME long radius nozzle discharge coefficients have been verified by a great number of experiments (Fig. 3G-28). Also, a reasonably accurate theoretical development of the discharge coefficient for this type of nozzle has been made using boundary layer theory (Ref. 30).

4.2.2 *Calculation Procedure*—Because the discharge coefficient is a function of Reynolds number, and thus of the flow, a small amount of iteration is involved in the computation. Using Eq. 3G-10,

$$W = \frac{C}{\sqrt{1-\beta^4}} Y_a A_2 \sqrt{2g(g\rho)_1(P_1-P_2)} \qquad (3G\text{-}15)$$

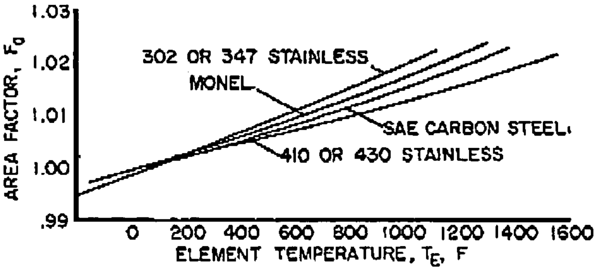


Fig. 3G-25—Correction factor for expansion of metering element

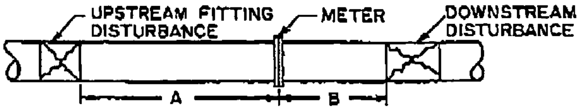


Table 3G-10 Disturbances Affecting Meter Installation

Disturbance Type	Minimum Straight Lengths, dia (a)	Minimum Straight Lengths, dia (b)
All types (except two or more upstream bends in different planes):		
β = 0.10–0.5	10	3
β = 0.60–0.70	18	4
For Upstream Bends in Different Planes:		
β = 0.10–0.4	18	3

proceed as follows:

(1) First make a reasonable guess at the nozzle flow and compute the Reynolds number from

$$N_{Re} = \frac{(g\rho)_1 VD}{\mu g} = \frac{4}{\pi \mu g}\left(\frac{W}{D}\right) \tag{3G-16}$$

For air, use Fig. 3G-29 as an aid. Obtain C from Fig. 3G-28.

(2) Compute the density from the upstream static pressure and temperature. For some liquids it may be desirable to make an experimental density determination with a hydrometer or other suitable instrument. Make humidity and compressibility corrections.

(3) If flow is compressible, using the β ratio and the nozzle pressures, determine Y_a from Fig. 3G-30 ($\gamma = 1.4$) as

$2|\gamma$

$$Y_a = \left[\left(\frac{P_1}{P_2}\right)^{2/\gamma}\left(\frac{\gamma}{\gamma-1}\right) \cdot \left(\frac{1-(P_2/P_1)\exp(\gamma-1/\gamma)}{1-(P_2/P_1)}\right) \cdot \left(\frac{1-\beta^4}{1-\beta^4(P_2/P_1)^{2/\gamma}}\right)\right]^{1/2}$$

Curves for other specific heat ratios

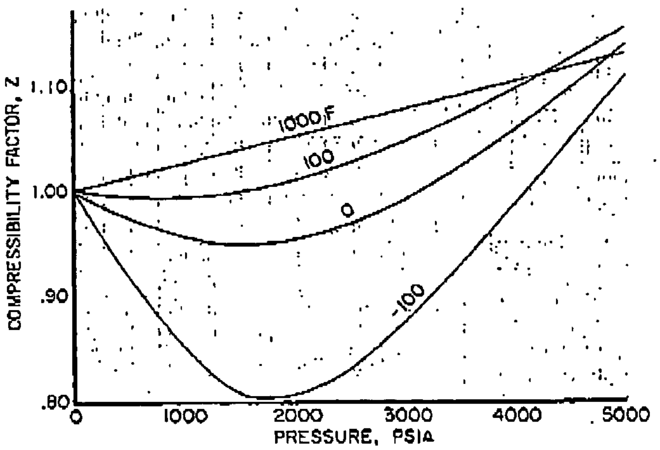


Fig. 3G-26—Compressibility factor for dry air. Based on data from Ref. 27

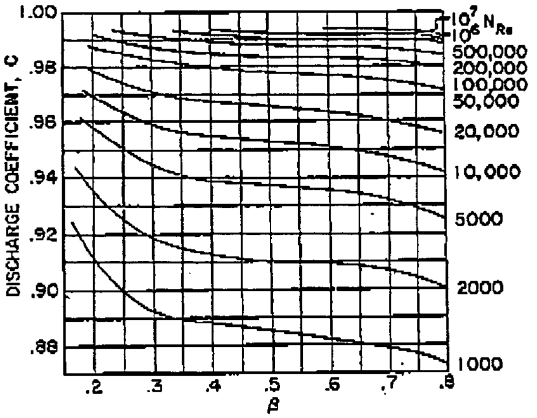


Fig. 3G-28—Discharge coefficients of ASME long radius nozzles with pipe wall tap

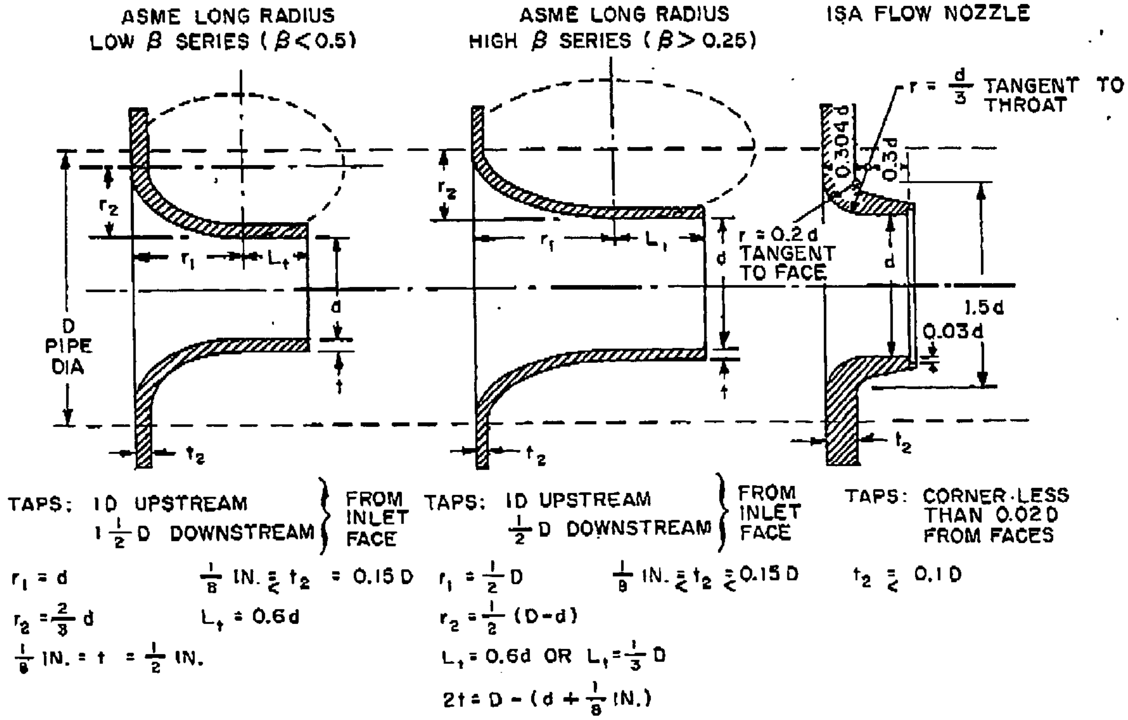

ASME LONG RADIUS LOW β SERIES (β<0.5)
ASME LONG RADIUS HIGH β SERIES (β>0.25)
ISA FLOW NOZZLE
r_2
r_1
L_t
d
t
D PIPE DIA
t_2
$r = \frac{d}{3}$ TANGENT TO THROAT
0.304d
0.3d
r = 0.2d TANGENT TO FACE
1.5d
0.03d
TAPS: 1D UPSTREAM, $1\frac{1}{2}$D DOWNSTREAM } FROM INLET FACE
TAPS: 1D UPSTREAM, $\frac{1}{2}$D DOWNSTREAM } FROM INLET FACE
TAPS: CORNER·LESS THAN 0.02D FROM FACES
$r_1 = d$
$\frac{1}{8}$ IN. $\leqq t_2$ = 0.15D
$r_2 = \frac{2}{3}d$
$L_t = 0.6d$
$\frac{1}{8}$ IN. = t = $\frac{1}{2}$ IN.
$r_1 = \frac{1}{2}D$
$\frac{1}{8}$ IN. $\leqq t_2 \leqq$ 0.15D
$r_2 = \frac{1}{2}(D-d)$
$L_t = 0.6d$ OR $L_t = \frac{1}{3}D$
$2t = D - (d + \frac{1}{8}$ IN.)
$t_2 \leqq$ 0.1D

Fig. 3G-27—Geometry of three common metering nozzles

are available in Ref. 1. Also see Fig. 3G-31, where for flange taps, plotted for $\gamma = 1.4$,

1—( )

$$Y_1 = (0.41 - 0.35\beta^4)\frac{P_1 - P_2}{P_1\gamma}$$

(4) Substituting in Eq. 3G-15, compute the flow. Recalculate the Reynolds number and obtain an improved value for the discharge coefficient. Improve the flow by the ratio of the new discharge coefficient to the original. Even when striving for high accuracy it is usually not necessary to repeat this process more than once.

Since C does not vary more than a few percent in the working range, in some cases it may be permissible to use a single value for C and neglect the Reynolds number effects. However, it is wise to examine carefully the impact of all terms in Eq. 3G-15, in view of each specific application, before deciding that any can be assumed constant.

4.2.3 *The Choked Nozzle*—As the Mach number in the nozzle throat approaches 1, Eq. 3G-10 tends to conceal the important variables, since it is purposely formulated as an incompressible flow equation with corrections for compressible flow. The equation may be rearranged as

$$\frac{W\sqrt{T_1}}{P_1A_2} = C\,\frac{\sqrt{\frac{2g}{R}\left(\frac{\gamma}{\gamma-1}\right)}\left[r^{2/\gamma}\left(1 - r^{\frac{\gamma-1}{\gamma}}\right)\right]^{1/2}}{\sqrt{1-\beta^4 r^{2/\gamma}}} \qquad \text{(3G-17)}$$

As the velocity at the throat approaches the acoustic velocity, the ratio of the throat static pressure to upstream static pressure becomes constant at a value of 0.528 for air, or greater, depending on the diameter ratio β. Beyond this point the throat pressure and the downstream pressure begin to diverge, but the flow is still governed by the fixed upstream-to-throat pressure ratio. Fig. 3G-32 depicts this behavior for nozzles and venturies. Fig. 3G-33 plots the data for orifices.

4.3 VENTURI TUBES

4.3.1 *Venturi Tube Design and Discharge Coefficients*—The classical

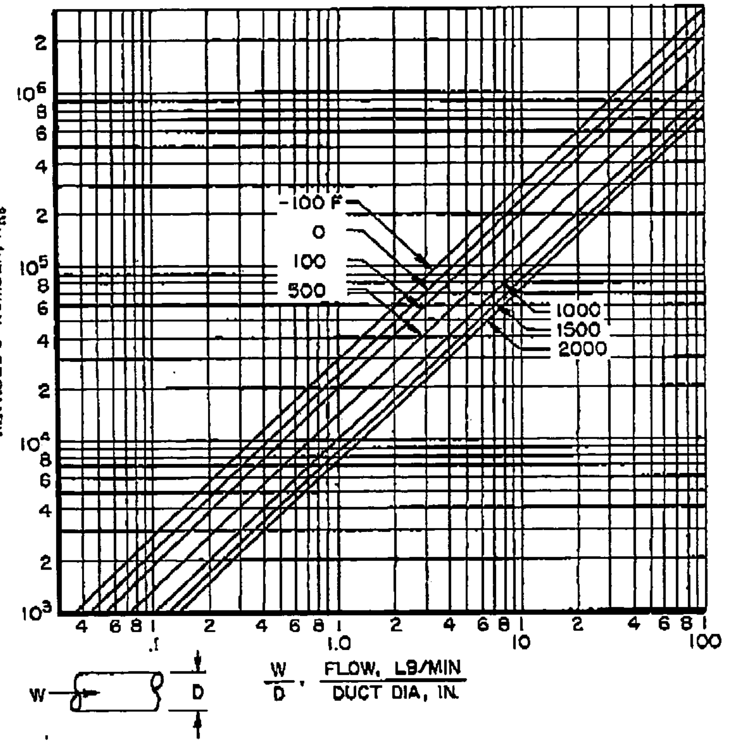


Fig. 3G-29—Reynolds number as a function of flow per inch of duct diameter for air

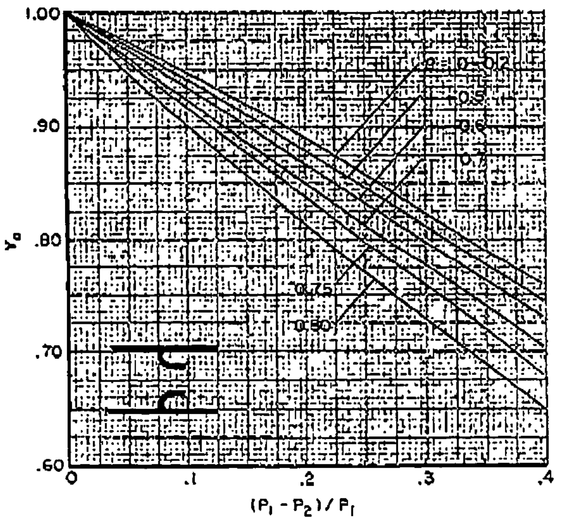


Fig. 3G-30—Expansion factor for nozzles and venturi tubes

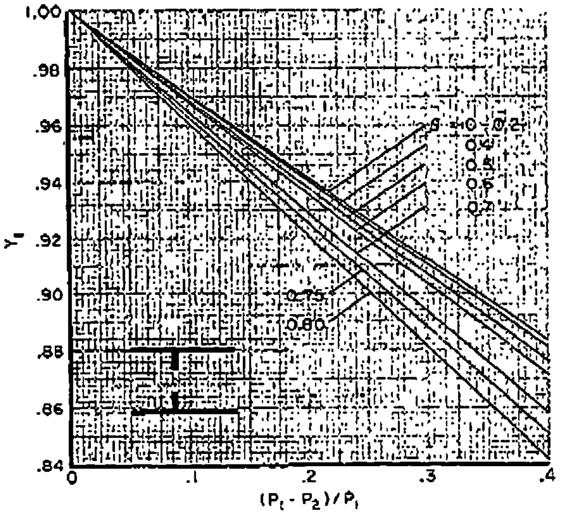


Fig. 3G-31—Expansion factor for sharp edged orifices

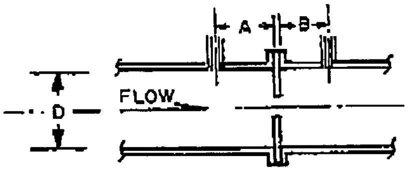
venturi design is widely used, although there are a number of variants (Fig. 3G-34). Perhaps the most interesting of these is the Dall tube, a highly individualistic form of the venturi with truncated approach and discharge sections (Ref. 31). The Dall tube has, for reasons yet unexplained, the lowest unrecoverable pressure loss of any of the acceleration type head meters.

The discharge coefficients of venturi tubes are governed by the same boundary layer phenomena as the flow nozzle, although the approach sections may not be similar. Discharge coefficients for the classical venturi tube are given in Fig. 3G-35.

4.3.2 *Venturi Tube Flow Computation*—The flow through a venturi tube is computed in the same manner as for a nozzle (Par. 4.2.2). Only the discharge coefficient is different for the two classes of devices. Computations for the choked venturi tube are also the same as for the nozzle (Fig. 3G-32).

4.4 ORIFICE METERS

4.4.1 *Orifice Meter Geometry and Flow Coefficients*—A typical sharp edge orifice meter installation is shown in Fig. 3G-36. A number of different kinds of taps are in common usage, as indicated in Table 3G-11, with reference to the illustration. Flange taps are probably the most widely used. Flow coefficients, K, for flange taps are given in Table 3G-11.



Often where some sacrifice in accuracy is permissible, an inlet or outlet orifice may be convenient (Ref. 32). For an inlet orifice [Fig. 3G-37(a)] the flow coefficient K is 0.601 for all β ratios (0.20:1.0). Tap location should be 0.4D downstream of the plate for $\beta < 0.6$. For higher β ratios the tap should be $(0.80 - 0.60\beta)D$ downstream of the plate. A good figure for the tolerance of such a device is not known, but it is probably 0.5–1.0%. For the outlet orifice [Fig. 3G-37(b)] with a tap 1 in. upstream of the orifice face, flange tap data may be used with reasonable accuracy (±0.5% tolerance).

4.4.2 *Orifice Flow Computation*—Recalling that the basic head meter equation for an orifice is written as

$$w = KY_1A_2\sqrt{2g(g\rho)_1(P_1 - P_2)} \tag{3G-18}$$

Table 3G-11 Kinds of Taps

Taps	A	B
Flange	1 in.	1 in.
Corner	0	0
Vena Contracta	1 dia	At vena contracta
Radius	1 dia	½ dia
Pipe	8 dia	2½ dia

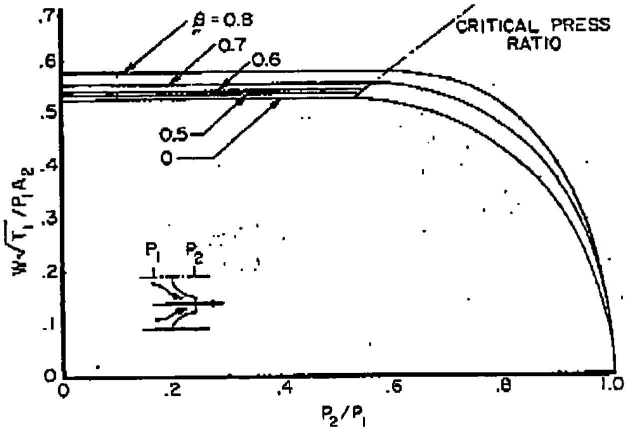


Fig. 3G-32—Flow factors for nozzles and venturis. W = lb/sec, T_1 = R, P_1 = psia, A_2 = nozzle or venturi throat area, in.^{2}. For air from Eq. 3G-17, C_{assumed} = 0.985, γ = 1.4

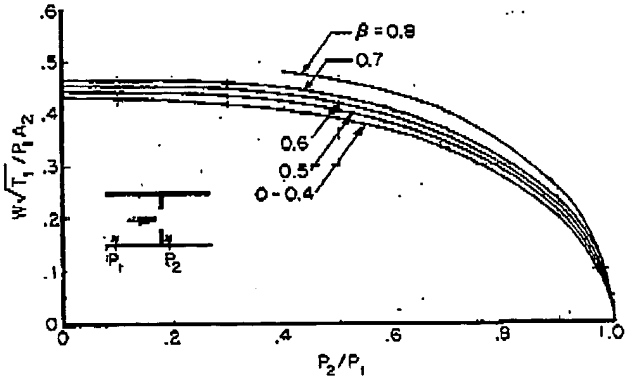


Fig. 3G-33—Flow factors for orifices. W = lb/sec, T_1 = R (total), P_1 = static pressure (D, upstream, psia), P_2 = corner tap, static downstream, psia, A_2 = orifice area. For air based on $W\sqrt{T_1}/P_1A_2 = (K\sqrt{2g/R})(Y\sqrt{1 - (P_2/P_1)})$ where K is taken for a 4 in. meter at N_{Re} = 10 (from Table 3G-1) and Y from Table 3G-2 as γ = 1.4

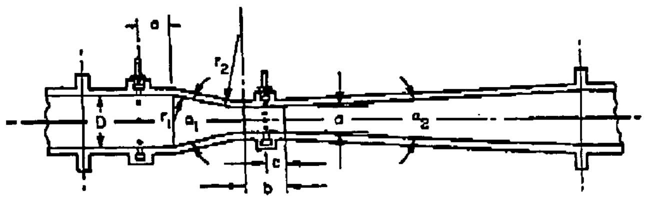
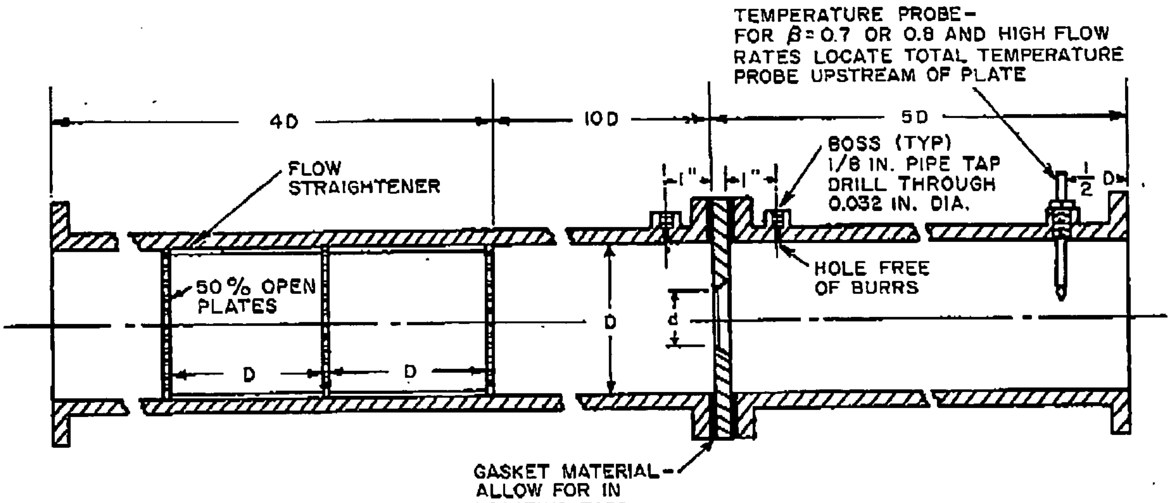
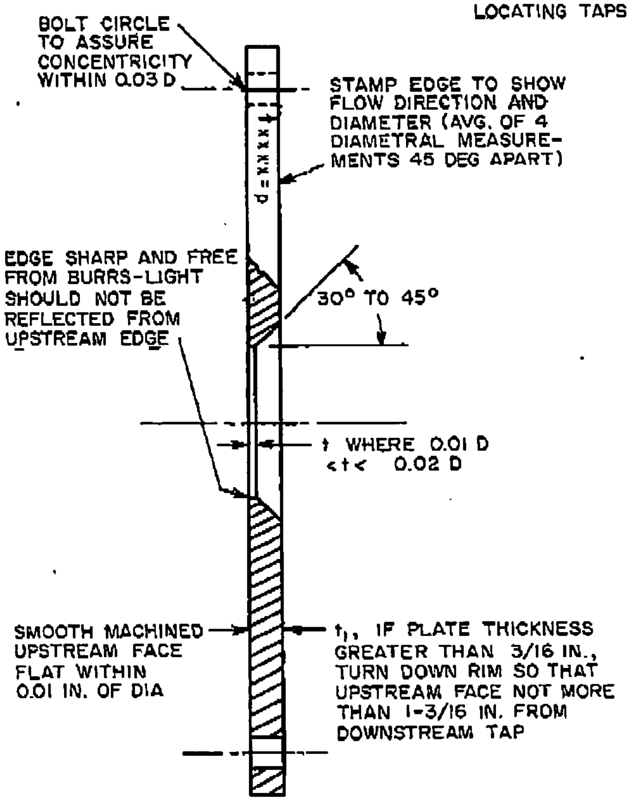


Fig. 3G-34—Geometry of Herschel type venturi tubes (annual piezometer rings to have at least four holes). a = 0.25D–0.75D for $4 \leq D \leq 6$ in. = 0.25D–0.50D for $6 \leq D \leq 32$ in., $b = d$, $c = d/2$, r_1 = 0–1.375D, r_a = 3.5d–3.75d, α_1 = 21 ± 2 deg, α_2 = 5–15 deg


TEMPERATURE PROBE-
FOR β = 0.7 OR 0.8 AND HIGH FLOW RATES LOCATE TOTAL TEMPERATURE PROBE UPSTREAM OF PLATE
4D
10D
5D
FLOW STRAIGHTENER
BOSS (TYP) 1/8 IN. PIPE TAP DRILL THROUGH 0.032 IN. DIA.
1"
1"
1/2 D
50% OPEN PLATES
D
d
HOLE FREE OF BURRS
D
D
GASKET MATERIAL-ALLOW FOR IN LOCATING TAPS


BOLT CIRCLE TO ASSURE CONCENTRICITY WITHIN 0.03 D
STAMP EDGE TO SHOW FLOW DIRECTION AND DIAMETER (AVG. OF 4 DIAMETRAL MEASUREMENTS 45 DEG APART)
d = X.XX
EDGE SHARP AND FREE FROM BURRS-LIGHT SHOULD NOT BE REFLECTED FROM UPSTREAM EDGE
30° TO 45°
t WHERE 0.01 D < t < 0.02 D
SMOOTH MACHINED UPSTREAM FACE FLAT WITHIN 0.01 IN. OF DIA
t₁, IF PLATE THICKNESS GREATER THAN 3/16 IN., TURN DOWN RIM SO THAT UPSTREAM FACE NOT MORE THAN 1-3/16 IN. FROM DOWNSTREAM TAP

ADDITIONAL RECOMMENDATIONS

1. Plate Material: Preferably corrosion resistant steel.
2. Small vent or drain holes should be provided near plate when measuring liquids containing small amounts of vapor, or vice versa.
3. Plate thickness (t_1): Recommendation (Ref. 28):

	t_1, in.	
Pipe *D*, in.	Temp 600 F	Temp 600 F
Up to 3	3/32 ± 1/32	1/4
4–6	5/32 ± 1/32	3/8
7–8	1/4 ± 1/16	1/2
10 and over	3/8 ± 1/8	1/2–3/4

Fig. 3G-36—A general purpose orifice meter section with details of orifice plate construction

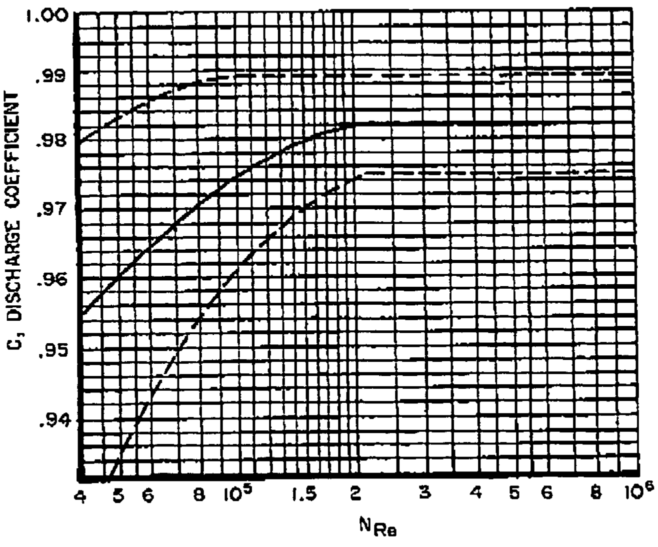


Fig. 3G-35—Discharge coefficients for Herschel type venturi tubes. (For β from 0.25 to 0.75 in pipes 2 in. or larger. Dotted lines indicate tolerance limits)

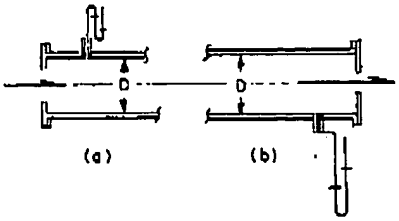


Fig. 3G-37—Orifice locations. (a) An inlet orifice; (b) an outlet orifice

the computational procedure is essentially the same as for a nozzle. With the basic test data (β, A_2, T_1, P_1, P_2), ($g\rho$) may be calculated and corrected if necessary, Y_1 found from Fig. 3G-31, and the Reynolds number estimated from Fig. 3G-29 or Eq. 3G-16. Entering Table 3G-12 with β and the estimated Reynolds number, K is found. Solving Eq. 3G-18 for correcting K, and subsequently w, by one or two iterations completes the calculation. Where many repetitive runs are being made, the meter user will probably find techniques for simplifying the calculations. For example, where P_1 and T_1 do not vary appreciably during the tests, plotting $KY_1A_2\sqrt{2g}$ as a function

Table 3G-12 Flange

(Values of the Flow Coefficient K, Velocity of Approach Factor Included, as a Function

For 1½ in. Pipe

β \ R_D	1,000	1,500	2,000	2,500	3,000	4,000	5,000	6,000	8,000	10,000	15,000	20,000	25,000	50,000	100,000	500,000	10^6
0.100	0.6116	0.6069	0.6076	0.6067	0.6062	0.6055	0.6052	0.6049	0.6045	0.6043	0.6040	0.6039	0.6038	0.6037	0.6036	0.6035	0.6035
.150	.6156	.6106	.6081	.6066	.6056	.6044	.6036	.6031	.6025	.6021	.6016	.6014	.6012	.6009	.6008	.6007	.6006
.200	.6214	.6140	.6103	.6081	.6066	.6047	.6036	.6029	.6020	.6014	.6007	.6003	.6001	.5996	.5994	.5992	.5991
.250	.6291	.6192	.6141	.6112	.6092	.6068	.6053	.6043	.6030	.6023	.6015	.6008	.6005	.5999	.5996	.5994	.5993
.300	.6383	.6255	.6190	.6152	.6126	.6094	.6075	.6062	.6046	.6036	.6023	.6017	.6013	.6005	.6001	.5998	.5998
.350	.6546	.6379	.6295	.6245	.6212	.6170	.6145	.6129	.6108	.6095	.6078	.6070	.6065	.6055	.6050	.6046	.6046
.400		.6536	.6426	.6360	.6317	.6262	.6229	.6207	.6179	.6163	.6141	.6130	.6124	.6110	.6104	.6099	.6098
.450		.6753	.6606	.6518	.6460	.6386	.6342	.6313	.6276	.6254	.6225	.6210	.6202	.6184	.6175	.6168	.6167
.500				.6733	.6654	.6555	.6495	.6455	.6406	.6376	.6336	.6317	.6305	.6281	.6269	.6259	.6258
.550				.7022	.6914	.6779	.6698	.6644	.6577	.6536	.6482	.6456	.6439	.6407	.6391	.6378	.6376
.600						.7076	.6968	.6895	.6804	.6749	.6675	.6639	.6617	.6573	.6551	.6533	.6531
.625						.7261	.7153	.7049	.6942	.6878	.6793	.6750	.6725	.6674	.6648	.6629	.6625
.650						.7468	.7320	.7231	.7096	.7024	.6925	.6876	.6846	.6787	.6757	.6734	.6731
.675						.7702	.7511	.7417	.7276	.7189	.7075	.7019	.6983	.6915	.6881	.6853	.6850
.700							.7769	.7637	.7473	.7374	.7242	.7177	.7137	.7058	.7019	.6987	.6983

For 2 in. Pipe

β \ R_D	1,000	2,000	3,000	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	50,000	100,000	500,000	10^6
0.100	0.6134	0.6085	0.6069	0.6062	0.6056	0.6053	0.6048	0.6046	0.6043	0.6041	0.6039	0.6037	0.6036	0.6035	0.6035
.150	.6172	.6082	.6052	.6038	.6029	.6023	.6016	.6011	.6005	.6002	.5999	.5997	.5995	.5983	.5983
.200		.6104	.6060	.6039	.6026	.6018	.6007	.6000	.5991	.5986	.5982	.5979	.5976	.5974	.5974
.250		.6149	.6092	.6064	.6047	.6035	.6021	.6012	.6001	.5995	.5990	.5985	.5982	.5979	.5979
.300		.6233	.6150	.6115	.6091	.6077	.6058	.6047	.6032	.6025	.6018	.6012	.6007	.6005	.6004
.350			.6331	.6183	.6155	.6138	.6130	.6099	.6089	.6070	.6061	.6053	.6049	.6043	.6042
.400			.6340	.6278	.6241	.6216	.6185	.6166	.6142	.6129	.6117	.6107	.6099	.6095	.6093
.450				.6409	.6359	.6325	.6284	.6259	.6225	.6209	.6192	.6179	.6169	.6161	.6160
.500				.6589	.6521	.6475	.6419	.6394	.6339	.6316	.6293	.6275	.6261	.6250	.6249
.550					.6742	.6679	.6600	.6555	.6490	.6458	.6426	.6402	.6384	.6363	.6366
.600					.7031	.6945	.6807	.6773	.6688	.6644	.6601	.6567	.6541	.6521	.6518
.625					.7210	.7110	.6984	.6910	.6809	.6759	.6708	.6668	.6638	.6634	.6611
.650						.7296	.7150	.7062	.6945	.6886	.6826	.6781	.6746	.6718	.6715
.675						.7505	.7338	.7238	.7095	.7028	.6962	.6908	.6868	.6836	.6832
.700						.7741	.7546	.7429	.7373	.7192	.7115	.7063	.7006	.6969	.6965

For 3 in. Pipe

β \ R_D	1,000	2,000	3,000	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	40,000	50,000	100,000	500,000	10^6
0.100	0.6120	0.6054	0.6032	0.6021	0.6016	0.6010	0.6004	0.6001	0.5996	0.5994	0.5992	0.5991	0.5990	0.5989	0.5988	0.5988
.150	.6186	.6069	.6030	.6010	.6000	.5993	.5983	.5975	.5967	.5963	.5961	.5959	.5958	.5955	.5953	.5953
.200	.6287	.6119	.6063	.6034	.6018	.6007	.5992	.5984	.5974	.5968	.5963	.5960	.5958	.5955	.5952	.5952
.250		.6189	.6118	.6081	.6060	.6045	.6027	.6017	.6002	.5994	.5988	.5984	.5982	.5978	.5974	.5974
.300		.6274	.6193	.6138	.6110	.6092	.6067	.6055	.6037	.6028	.6019	.6014	.6012	.6007	.6002	.6002
.350			.6270	.6212	.6175	.6152	.6123	.6106	.6085	.6073	.6061	.6055	.6052	.6045	.6039	.6039
.400			.6370	.6314	.6270	.6239	.6201	.6178	.6147	.6132	.6117	.6109	.6104	.6094	.6089	.6088
.450				.6459	.6398	.6356	.6306	.6275	.6233	.6213	.6192	.6187	.6175	.6163	.6153	.6152
.500				.6666	.6580	.6524	.6444	.6405	.6351	.6322	.6294	.6280	.6271	.6254	.6241	.6239
.550				.6855	.6832	.6751	.6651	.6591	.6510	.6471	.6427	.6410	.6398	.6369	.6354	.6352
.600				.7335	.7168	.7056	.6917	.6834	.6732	.6666	.6610	.6513	.6566	.6532	.6506	.6502
.625				.7571	.7375	.7244	.7080	.6982	.6850	.6785	.6719	.6686	.6667	.6528	.6596	.6594
.650				.7843	.7613	.7459	.7266	.7151	.6998	.6923	.6845	.6805	.6782	.6737	.6700	.6695
.675				.8150	.7881	.7702	.7477	.7343	.7163	.7073	.6983	.6938	.6911	.6858	.6815	.6809
.700				.8469	.8186	.7977	.7715	.7599	.7350	.7245	.7140	.7091	.7058	.6996	.6946	.6939

For 4 in. Pipe

β \ R_D	1,000	2,000	3,000	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	40,000	50,000	100,000	500,000	10^6
0.100	0.6118	0.6035	0.6010	0.5996	0.5988	0.5983	0.5975	0.5971	0.5967	0.5964	0.5961	0.5960	0.5959	0.5958	0.5957	0.5956
.150	.6223	.6050	.6013	.6009	.5995	.5986	.5976	.5966	.5956	.5951	.5947	.5944	.5943	.5941	.5940	.5939
.200		.6151	.6084	.6050	.6030	.6017	.6000	.5990	.5977	.5970	.5963	.5960	.5958	.5955	.5951	.5950
.250		.6230	.6144	.6102	.6076	.6059	.6018	.6015	.6006	.5995	.5989	.5987	.5984	.5979	.5975	.5974
.300		.6317	.6212	.6160	.6128	.6107	.6081	.6065	.6044	.6034	.6023	.6018	.6015	.6009	.6003	.6002
.350			.6300	.6236	.6195	.6168	.6135	.6116	.6090	.6076	.6064	.6057	.6053	.6045	.6039	.6038
.400			.6429	.6343	.6291	.6257	.6214	.6188	.6152	.6135	.6119	.6110	.6105	.6094	.6086	.6085
.450				.6503	.6431	.6384	.6324	.6289	.6242	.6218	.6194	.6182	.6175	.6161	.6150	.6148
.500				.6731	.6631	.6564	.6483	.6431	.6364	.6330	.6296	.6281	.6271	.6251	.6235	.6233
.550					.6883	.6793	.6692	.6625	.6535	.6484	.6439	.6413	.6400	.6371	.6350	.6347
.600					.7292	.7158	.6991	.6891	.6757	.6690	.6623	.6590	.6569	.6530	.6498	.6494
.625					.7530	.7371	.7175	.7054	.6896	.6817	.6737	.6698	.6674	.6626	.6588	.6584
.650					.7798	.7611	.7378	.7218	.7054	.6958	.6864	.6818	.6790	.6735	.6690	.6684
.675					.8106	.7884	.7613	.7448	.7229	.7130	.7020	.6956	.6933	.6857	.6804	.6797
.700					.8434	.8197	.7878	.7685	.7428	.7301	.7173	.7109	.7071	.6994	.6932	.6925
.725						.8554	.8182	.7958	.7760	.7513	.7362	.7288	.7253	.7163	.7081	.7073
.750						.8993	.8557	.8295	.7946	.7774	.7600	.7513	.7461	.7356	.7272	.7262

Note: All values given below the heavily stepped line are extrapolations of meter ΔP will eliminate the iteration.

4.4.3 *Flow Computation for Orifices with Supercritical Pressure Ratios*—Unlike the choked nozzle, the orifice "throat area" at the vena contracta is unbounded. This section tends to expand at supercritical pressure ratios and the flow continues to increase with decreasing pressure ratio r. Flow computations for the orifice in this regime may be made from Fig. 3G-33. There is evidence (Ref. 34) that thick plate orifices, those considerably thicker than the permissible ASME dimensions of Fig. 3G-36, will behave more like a nozzle, though with a somewhat lower discharge coefficient.

4.5 TOLERANCES—The tolerance, or "limit of reliance," has been defined (Ref. 25) for fluid meter work as equal to twice the standard deviation of the experimental observations on which the coefficient values are based. The tolerances for the flange tap orifice flow coefficients are given in Table 3G-13.

For nozzles, the tolerances for the discharge coefficients (Fig. 3G-28).

Taps
of the Pipe Reynolds Number N_{R_e} and Diameter Ratio β).

For 6 in. Pipe

N_{R_e} \ β	2,000	3,000	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	50,000	100,000	500,000	10^6	10^7
0.100	0.6040	0.6001	0.5984	0.5973	0.5965	0.5956	0.5950	0.5942	0.5938	0.5934	0.5931	0.5929	0.5927	0.5927	0.5927
.150		.6065	.6053	.6014	.6000	.5984	.5974	.5961	.5955	.5949	.5943	.5938	.5936	.5935	.5934
.200			.6088	.6061	.6043	.6021	.6008	.5990	.5981	.5972	.5965	.5960	.5955	.5955	.5954
.250				.6105	.6066	.6038	.6042	.6020	.6009	.5998	.5990	.5982	.5977	.5976	.5975
.300					.6133	.6100	.6091	.6065	.6061	.6028	.6018	.6012	.6003	.6002	.6001
.350					.6199	.6159	.6135	.6103	.6087	.6071	.6055	.6048	.6040	.6039	.6038
.400						.6341	.6209	.6166	.6145	.6134	.6107	.6095	.6085	.6083	.6082
.450						.6366	.6323	.6263	.6233	.6202	.6179	.6161	.6145	.6146	.6144
.500							.6481	.6396	.6354	.6311	.6276	.6250	.6231	.6228	.6226
.550							.6708	.6583	.6521	.6459	.6410	.6372	.6343	.6339	.6336
.600							.7014	.6856	.6747	.6658	.6587	.6513	.6490	.6484	.6481
.625							.7207	.6999	.6887	.6781	.6695	.6632	.6580	.6575	.6568
.650							.7425	.7171	.7044	.6918	.6817	.6741	.6681	.6673	.6666
.675							.7673	.7374	.7214	.7074	.6954	.6857	.6795	.6785	.6778
.700							.7952	.7600	.7425	.7254	.7109	.7005	.6919	.6908	.6898
.725							.8274	.7862	.7666	.7451	.7306	.7165	.7067	.7053	.7041
.750							.8658	.8179	.7937	.7698	.7505	.7361	.7246	.7231	.7219

For 8 in. Pipe

N_{R_e} \ β	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	40,000	50,000	75,000	100,000	500,000	10^6	10^7
0.100	0.5991	0.5977	0.5968	0.5956	0.5949	0.5940	0.5935	0.5930	0.5928	0.5926	0.5924	0.5923	0.5921	0.5920	0.5920
.150	.6039	.6034	.6018	.5998	.5986	.5969	.5961	.5952	.5948	.5946	.5943	.5942	.5938	.5937	.5937
.200	.6128	.6088	.6066	.6019	.6022	.6000	.5989	.5977	.5972	.5969	.5965	.5963	.5958	.5957	.5957
.250	.6174	.6135	.6108	.6075	.6056	.6029	.6016	.6005	.5995	.5993	.5987	.5984	.5978	.5977	.5976
.300	.6236	.6189	.6158	.6119	.6096	.6065	.6049	.6034	.6027	.6022	.6016	.6013	.6006	.6004	.6003
.350		.6266	.6227	.6179	.6151	.6112	.6091	.6073	.6066	.6059	.6051	.6047	.6038	.6037	.6036
.400		.6377	.6328	.6266	.6229	.6180	.6155	.6130	.6119	.6110	.6100	.6095	.6084	.6083	.6081
.450		.6555	.6486	.6400	.6348	.6278	.6243	.6209	.6192	.6181	.6168	.6161	.6146	.6143	.6142
.500			.6729	.6603	.6527	.6425	.6373	.6325	.6299	.6284	.6262	.6252	.6229	.6226	.6223
.550			.7080	.6892	.6780	.6631	.6556	.6481	.6445	.6422	.6391	.6376	.6341	.6336	.6332
.600			.7570	.7236	.7131	.6912	.6803	.6691	.6638	.6605	.6561	.6539	.6486	.6480	.6474
.625				.7551	.7353	.7088	.6956	.6824	.6758	.6719	.6666	.6640	.6575	.6567	.6560
.650				.7839	.7600	.7287	.7129	.6971	.6894	.6847	.6783	.6751	.6676	.6667	.6658
.675				.8069	.7889	.7515	.7329	.7142	.7048	.6992	.6917	.6880	.6790	.6779	.6768
.700				.8547	.8212	.7772	.7552	.7332	.7221	.7154	.7067	.7023	.6918	.6904	.6892
.725					.8585	.8067	.7808	.7548	.7418	.7340	.7237	.7185	.7063	.7046	.7032
.750					.9022	.8416	.8111	.7809	.7656	.7565	.7444	.7383	.7272	.7218	.7202

For 10 in. Pipe

N_{R_e} \ β	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	40,000	50,000	75,000	100,000	200,000	500,000	10^6	10^7
0.100	0.6015	0.5998	0.5976	0.5962	0.5953	0.5942	0.5936	0.5930	0.5927	0.5926	0.5923	0.5922	0.5920	0.5919	0.5919	0.5919
.150	.6085	.6035	.6016	.6005	.5995	.5975	.5966	.5958	.5953	.5950	.5946	.5944	.5941	.5939	.5939	.5938
.200	.6151	.6112	.6087	.6054	.6015	.6009	.5996	.5983	.5977	.5972	.5967	.5965	.5961	.5959	.5958	.5957
.250	.6207	.6162	.6131	.6092	.6069	.6042	.6027	.6012	.6004	.6000	.5991	.5988	.5983	.5980	.5979	.5978
.300	.6268	.6215	.6180	.6136	.6110	.6074	.6056	.6039	.6032	.6025	.6019	.6015	.6010	.6007	.6006	.6005
.350		.6290	.6248	.6196	.6164	.6129	.6100	.6079	.6069	.6063	.6056	.6050	.6044	.6040	.6039	.6038
.400		.6411	.6356	.6287	.6246	.6191	.6163	.6147	.6122	.6114	.6102	.6097	.6089	.6084	.6083	.6081
.450		.6608	.6530	.6455	.6374	.6296	.6257	.6218	.6199	.6187	.6172	.6163	.6152	.6144	.6142	.6140
.500		.6917	.6801	.6656	.6570	.6454	.6396	.6337	.6307	.6291	.6268	.6257	.6239	.6229	.6226	.6223
.550			.7200	.6980	.6857	.6681	.6593	.6505	.6461	.6435	.6399	.6381	.6355	.6339	.6334	.6339
.600			.7765	.7441	.7247	.6988	.6859	.6728	.6665	.6626	.6575	.6548	.6509	.6486	.6478	.6471
.625			.8108	.7720	.7487	.7176	.7021	.6865	.6789	.6743	.6680	.6649	.6602	.6575	.6566	.6557
.650				.8069	.7778	.7404	.7216	.7028	.6934	.6878	.6804	.6766	.6710	.6676	.6665	.6655
.675				.8459	.8104	.7656	.7432	.7200	.7028	.7031	.6951	.6895	.6828	.6788	.6775	.6762
.700					.8474	.7943	.7678	.7413	.7281	.7201	.7095	.7042	.6963	.6915	.6899	.6885
.725					.8897	.8373	.7960	.7647	.7492	.7397	.7276	.7210	.7116	.7060	.7055	.7024
.750					.9370	.8644	.8315	.7753	.7577	.7408	.7321	.7299	.7245	.7213	.7202	.7190

For 14.14 in. *ID* Pipe

N_{R_e} \ β	4,000	5,000	6,000	8,000	10,000	15,000	20,000	30,000	40,000	50,000	75,000	100,000	200,000	500,000	10^6	10^7
0.100	0.6039	0.6015	0.6000	0.5980	0.5968	0.5952	0.5945	0.5937	0.5933	0.5931	0.5928	0.5926	0.5924	0.5922	0.5921	0.5920
.150	.6136	.6097	.6070	.6038	.6018	.5992	.5989	.5971	.5966	.5959	.5955	.5951	.5948	.5944	.5941	.5940
.200	.6212	.6162	.6128	.6088	.6061	.6027	.6010	.5996	.5983	.5980	.5975	.5970	.5965	.5962	.5961	.5960
.250	.6271	.6212	.6174	.6125	.6096	.6063	.6038	.6019	.6007	.6004	.5996	.5992	.5986	.5983	.5982	.5981
.300		.6262	.6219	.6165	.6131	.6090	.6068	.6047	.6036	.6030	.6021	.6017	.6010	.6006	.6005	.6008
.350			.6288	.6225	.6187	.6137	.6112	.6086	.6074	.6066	.6056	.6051	.6044	.6039	.6037	.6036
.400			.6407	.6326	.6297	.6212	.6179	.6146	.6130	.6120	.6107	.6101	.6091	.6085	.6083	.6081
.450				.6496	.6425	.6330	.6282	.6235	.6211	.6197	.6178	.6168	.6155	.6145	.6143	.6140
.500				.6764	.6655	.6510	.6437	.6364	.6328	.6306	.6277	.6263	.6241	.6228	.6224	.6220
.550					.7002	.6777	.6664	.6552	.6496	.6462	.6417	.6394	.6361	.6340	.6333	.6327
.600					.7478	.7141	.6973	.6804	.6720	.6669	.6601	.6568	.6518	.6487	.6479	.6468
.625					.7785	.7374	.7167	.6962	.6859	.6798	.6716	.6675	.6615	.6577	.6564	.6553
.650					.8133	.7638	.7391	.7143	.7019	.6945	.6846	.6797	.6722	.6678	.6663	.6650
.675						.7942	.7645	.7348	.7199	.7111	.6992	.6933	.6844	.6790	.6772	.6756
.700						.8287	.7935	.7582	.7405	.7299	.7158	.7089	.6982	.6918	.6897	.6878
.725						.8681	.8224	.7846	.7639	.7513	.7345	.7262	.7137	.7062	.7036	.7014
.750						.9140	.8724	.8207	.7949	.7793	.7587	.7484	.7319	.7236	.7205	.7177

and are subject to the double tolerances of Table 3G-13.